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Research Note

# Supplemental Atmospheres

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METEOROLOGICAL DEVELOPMENT LABORATORY PROJECT 8624

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES, OFFICE OF AEROSPACE RESEARCH, UNITED STATES AIR FORCE, L.G. HANSCOM FIELD, MASS.

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## Abstract

Atmospheres typical of the tropics (15°N), sub-tropics (30°N), and mid-latitudes (45°N) have been prepared as members of a family of atmospheres supplemental to the 1962 U. S. Standard Atmosphere; they provide information on latitudinal and seasonal changes in atmospheric structure up to 90 km.

Temperature gradients for various segments are linear with geopotential height. Humidity is incorporated into the lowermost 10 km of each atmosphere. Figures and tables depict temperature, relative humidity, pressure, and density.

The atmospheres are mutually consistent; zonal wind profiles computed from the geostrophic wind equation at selected pressure heights compare favorably with existing rawinsonde and Meteorological Rocket Network wind observations.

The tropical atmosphere has a surface temperature of 26.5°C and a trade-wind inversion, 250 m thick, of 0.8°C at 2250 m, and a sharp tropopause inversion at 16.5 km with a minimum temperature of -80°C; it has isothermal regions at -3°C from 47 to 51 km and at -89°C from 80 to 90 km.

Subtropical winter and summer temperature-height profiles have surface temperatures of 14°C and 28°C, respectively, and three isothermal layers: -70°C at 17 to 18 km in winter and 15 to 16 km in summer; -4°C in winter and -0.5°C in summer, both at 47 to 51 km; -82°C in winter and -94.5°C in summer, both at 80 to 90 km.

Mid-latitude winter and summer profiles begin with surface temperature of -1°C and 21°C, respectively, and contain three isothermal regions: -58°C at 19 to 27 km in winter and -57.5°C at 13 to 17 km in summer; -7.5°C and 2.5°C at 47 to 52 km; and -79.5°C and -99°C at 80 to 90 km in winter and summer, respectively.

## Contents

## Tables

## Illustrations

## Foreword

The revised "U. S. Standard Atmosphere, 1962," extending to 700 km was adopted on 15 March 1962 by the U. S. Committee on Extension to the Standard Atmosphere (COESA), representing 29 U. S. scientific and engineering organizations. The Atmosphere is intended to permit estimation of the effects of the atmosphere on certain design and performance criteria of objects traveling through it, as well as to serve as a mid-latitude reference against which new measurements of atmospheric properties can be compared.

To satisfy the many requests for description of latitudinal and seasonal changes to a height of at least 90 km, not distinguished in a single Standard, an attempt has been made to incorporate systematically the relatively few observations available above 30 km into an internally consistent family of atmospheric models. Although much less detailed than the U. S. Standard Atmosphere, 1962, these models combined into a north-south vertical cross section serve to illustrate latitudinal and winter-summer atmospheric variations.

The Tropical, Subtropical and Mid-latitude Atmospheres described in this report were reviewed at a COESA working group meeting in June, 1962. A task group was appointed to investigate new data, and to revise and extend these models to the subarctic and arctic so that eventually a complete series of supplemental atmospheres can be adopted by COESA and published as an appendix to the U. S. Standard Atmosphere through the Government Printing Office.

| | | |
|---|---|---|
| Maurice Dubin | Norman Sissenwine | Harry Wexler |
| NASA | GRD, AFCRL | USWB |

Co-Chairmen, U. S. Committee on Extension to the Standard Atmosphere
June 1962

# Supplemental Atmospheres

## 1 INTRODUCTION

A mean annual Tropical (15°N) Atmosphere and summer and winter Subtropical (30°N) and Mid-latitude (45°N) Atmospheres described in this report define atmospheric structure typical of tropical, subtropical and middle latitudes in the Northern Hemisphere. These atmospheres belong to a family of nine atmospheres which are being constructed at 15° latitude intervals from 15° through 75°N to supplement the U. S. Standard Atmosphere, 1962. They reflect the seasonal and latitudinal variability of density, temperature and pressure, thus amplifying the description provided by the U. S. Standard. As in the Standard, the latest internationally adopted values of the various thermodynamic and physical constants have been used in all equations for computing atmospheric properties (Cole et al, 1961). Each supplemental atmosphere retains the value for the acceleration due to gravity corresponding to its latitude decreasing with height according to Lambert's (1951) formula:

| | | |
|---|---|---|
| Tropical: | 978.381 | $cm/sec^2$ |
| Subtropical: | 979.324 | $cm/sec^2$ |
| Mid-latitude: | 980.665 | $cm/sec^2$ |

The defining parameter up to at least 80 km is atmospheric temperature with linear gradients in geopotential meters exact to tenths of a Celsius degree. Humidity has been specified at appropriate levels in all five atmospheres. Mean values of relative humidity, ambient temperature, and resulting virtual temperatures for the lowermost 10 km of each atmosphere are shown

(Received for publication 17 August 1962)

in Table 4. Above 10 km the differences between virtual and ambient temperatures are insignificant since relative humidity less than 30 percent produces a negligible virtual temperature increment at the colder temperatures.

The derived virtual temperature gradients depart from linearity so slightly that errors in pressure, assuming linearity, are insignificant over 1- and 2-km layers. Vertical pressure and density distributions were calculated for each atmosphere according to its assumed moisture content from the hydrostatic equation and the equation of state (Cole and Kantor, 1962; Kantor and Cole, 1962).

## 2 DATA

Data available for constructing the various atmospheres consisted of: (1) summaries of radiosonde observations at stations within a few degrees of latitudes 15°, 30°, and 45°N; (2) density measurements from searchlight observations in New Mexico; and (3) observations made from rockets and instruments released by rockets fired at ranges in California, Florida, New Mexico, Virginia, and Guam (all between 13° and 38°N), at Churchill, Canada (59°N), in Australia (33°S), at the equator, and aboard ships. Data sources are given in the Appendix.

Below 30 km realistic mean January and July temperatures for latitudes 30° and 45°N and mean annual temperatures for 15°N were obtained by giving equal weight to radiosonde observations and interpolated data over both land and ocean areas at each ten degrees of longitude. Above 30 km the temperature-height profiles were based on mean seasonal latitudinal temperature-height cross sections between 15° and 60°N (Fig.1), prepared from all available rocket and searchlight observations of temperature, pressure, and density between 30 and 90 km. Winter and summer temperatures for 60°N are preliminary and appear on the cross section solely for comparison with the proposed 15°, 30°, and 45°N structure. Additional research is underway in order to determine more accurately the vertical temperature distribution and variability at latitude 60°N and 75°N, particularly during the winter months.

Sea-level pressures for each atmosphere were estimated from monthly normal sea-level charts for the Northern Hemisphere (USWB, 1952) based upon a 40-year period of record, and from 5-day normal sea-level charts (Lahey et al, 1958) based upon a 20-year period of record. Mean hemispheric sea-level pressures selected for the various atmospheres are shown in Tables 1, 2, and 3.

## 3 DESCRIPTION

A mean annual atmosphere rather than seasonal atmospheres was adopted for 15°N since the temperature-height structure in the tropics remains relatively constant throughout the year. The largest seasonal variability in temperature (3° - 5°) occurs near the tropopause which is about 1 km higher in January than in July. Routine averaging by height of available data indicates an isothermal layer about 2 km thick from 16 to 18 km; averaging of tropopause height and temperature, and of conditions above and below it, however, depicts a sharp inversion. As a result, the mean annual profile has a tropopause, 16.5 geopotential km, more typical of actual conditions.

Latitude 15°N lies in the heart of the trade-wind belt characterized by a trade-wind inversion through most of the year. To represent the average height and magnitude of this inversion, the mean annual temperature-height profile has a 0.8°C temperature inversion between 2250 and 2500 meters. The Tropical Atmosphere is considered representative of the entire region between the equator and 15°N because differences in mean temperature between 15°N and the equator are no larger than between various longitudes along 15°N.

The temperature-height profiles for 30° and 45°N atmospheres are compared with the mean annual 15°N atmosphere in Figure 2 for winter and summer. In Figure 3 each atmosphere is shown with the U. S. Standard, and in addition the tropical atmosphere is compared to temperature-height curves for three other atmospheres:

1. MIL-STD 210A, <u>Tropical Atmosphere</u> (DOD, 1957)
2. <u>Tropical Atmosphere</u>, proposed by Pisharoty (1959)
3. <u>A Low-latitude Atmosphere</u>, prepared by Nordberg and Stroud (1961).

All four low-latitude profiles are in close agreement reflecting the homogeneity of the tropical climate.

## 4 DENSITIES

Densities for the proposed Tropical, Subtropical, and Mid-latitude Atmospheres are shown in Figure 4, as percent departures from the 1962

U. S. Standard. Also depicted with the 15°N atmosphere are density departures for the MIL-STD 210A Tropical Atmosphere.

Comparisons for both 15° and 30°N are based on densities at even geopotential altitudes. However, geometric height of a given geopotential surface decreases with increasing latitude: the 50 geopotential km surface at latitudes 15° and 30° N occurs at 50.480 and 50.432 geometric km, respectively. The percentage departures shown in Figure 4 at geopotential heights are therefore slightly different than those at geometric heights. The differences at 90 km, the altitude at which the largest discrepancey exists, is roughly 2 to 3 percent.

Based on rocket and searchlight observations, estimates of the day-to-day (inter-diurnal) variability exceeded less than 5 percent of the time above 30 km are shown in Figure 4 for 30°N (horizontal arrows). Minimum seasonal and inter-diurnal variability at 8 km represents the isopycnic level where density remains relatively constant throughout the year regardless of location. A second isopycnic level may exist near 90 km, at which seasonal density profiles at all latitudes appear to approach or cross the Standard (Cole, 1961); the limited number of observations at this altitude also indicates a decrease in inter-diurnal variability.

At 45°N densities are not symmetric about the Standard at most heights: the summertime departures are larger than those of winter, particularly above 8 km. Below 30 km, where data are plentiful, mean annual densities based on all months (or four seasons) approach the Standard, whereas those averaged for winter and summer values do not. Since similar conditions probably exist between 30 and 90 km, the annual variation of density, to at least 90 km, is not linear at 45°N.

## 5 VALIDITY

January and July geostrophic zonal wind components were estimated between 25° and 30°N, and 30° and 45°N, using latitudinal pressure gradients computed from the Tropical, Subtropical and Mid-latitude Atmospheres. These estimates are compared in Figure 5 with appropriate Meteorological Rocket Network zonal wind observations (Bruch and Morgan, 1961, USASMSA, 1959-1961) above 30 km, and with serially complete tabulations of rawinsonde observations for the period 1951-1956 (Charles, 1956) below 30 km.

For further comparison geostrophic winds were also computed between 25°

and 30°N (Fig. 5), using seasonal tropical data. The slightly better agreement of computed and observed winds using seasonally computed pressure-heights at 15°N in contrast to that using mean annual values at 15°N does not warrant development of seasonal atmospheres at 15°N at this time.

The five supplemental atmospheres are mutually consistent. Temperatures, pressures, and densities versus geopotential and geometric altitudes are provided for each atmosphere at heights up to 90 km (Tables 1, 2, and 3).

TheTropical Atmosphere represents mean annual conditions at 15°N, a region with little seasonal variability; the Subtropical and Mid-Latitude Atmospheres depict mean winter and summer conditions at 30° and 45°N, respectively. At latitude 45°N, however, and to some extent 30°N, longitudinal variations in mean winter and summer temperatures are significant up to heights of about 15 km, reflecting hemispheric continental and maritime influences. Winter temperatures over continents can be as much as 50°C lower than that over oceans at the surface, and 10°C near 15 km. Thus, suitability of mean seasonal atmospheric structure in the lower most 15 km must bc carefully determined when used for specified location and/or purposes.

Table 1. Properties to 90 Km of Mid-Latitude (45°N) Atmosphere, Winter and Summer.

| Kilometers | | Temp. Grad. | | Temp. (K) | | Pressure (mbs) | | Density ( g / m$^3$ ) | |
|---|---|---|---|---|---|---|---|---|---|
| Geomet | Geopot | Win | Sum | Win | Sum | Win | Sum * | Win | Sum * |
| 90.000 | 88.743 | 0.0 | 0.0 | 204.15 | 174.15 | 1.9472 | 1.7975 -3 | 3.3229 | 3.5957 -3 |
| 89.235 | 88.000 | 0.0 | 0.0 | 204.15 | 174.15 | 2.2051 | 2.0796 | 3.7628 | 4.1600 |
| 87.179 | 86.000 | 0.0 | 0.0 | 204.15 | 174.15 | 3.0816 | 3.0787 | 5.2586 | 6.1587 |
| 85.125 | 84.000 | 0.0 | 0.0 | 204.15 | 174.15 | 4.3066 | 4.5579 | 7.3490 | 9.1177 -3 |
| 83.072 | 82.000 | 0.0 | 0.0 | 204.15 | 174.15 | 6.0184 | 6.7478 | 1.0270 | 1.3498 -2 |
| 81.020 | 80.000 | 0.0 | 0.0 | 204.15 | 174.15 | 8.4108 | 9.9898 -3 | 1.4353 | 1.9984 |
| 79.994 | 79.000 | xxx | xxx | 204.15 | 174.15 | 0.9943 | 1.2155 -2 | 1.6967 | 2.4315 |
| 78.969 | 78.000 | -2.5 | -4.5 | 206.65 | 178.65 | 1.1742 | 1.4753 | 1.9795 | 2.8769 |
| 76.920 | 76.000 | -2.5 | -4.5 | 211.65 | 186.65 | 1.6279 | 2.1426 | 2.6795 | 3.9777 |
| 74.872 | 74.000 | -2.5 | -4.5 | 216.65 | 196.65 | 2.2398 | 3.0577 | 3.6016 | 5.4168 |
| 72.825 | 72.000 | -2.5 | -4.5 | 221.65 | 205.65 | 3.0593 | 4.2948 | 4.8084 | 7.2754 |
| 70.779 | 70.000 | -2.5 | -4.5 | 226.65 | 214.65 | 4.1497 | 5.9453 | 6.3783 | 9.6491 -2 |
| 68.735 | 68.000 | -2.5 | -4.5 | 231.65 | 223.65 | 5.5913 | 8.1207 -2 | 0.8409 | 1.2649 -1 |
| 66.692 | 66.000 | -2.5 | -4.5 | 236.65 | 232.65 | 0.7486 | 1.0931 -1 | 1.1020 | 1.6368 |
| 64.651 | 64.000 | xxx | -4.5 | 241.65 | 241.65 | 0.9962 | 1.4616 | 1.4361 | 2.1071 |
| 62.611 | 62.000 | -2.0 | xxx | 245.65 | 250.65 | 1.3187 | 1.9292 | 1.8701 | 2.6813 |
| 60.572 | 60.000 | -2.0 | -2.5 | 249.65 | 255.65 | 1.7376 | 2.5270 | 2.4247 | 3.4435 |
| 58.534 | 58.000 | -2.0 | -2.5 | 253.65 | 260.65 | 2.2797 | 3.2928 | 3.1310 | 4.4010 |
| 56.498 | 56.000 | -2.0 | -2.5 | 257.65 | 265.65 | 2.9782 | 4.2690 | 4.0269 | 5.5983 |
| 54.463 | 54.000 | -2.0 | -2.5 | 261.65 | 270.65 | 3.8747 | 5.5080 | 5.1589 | 7.0897 |
| 52.429 | 52.000 | xxx | xxx | 265.65 | 275.65 | 5.0210 | 7.0735 | 6.5845 | 8.9396 -1 |
| 50.396 | 50.000 | 0.0 | 0.0 | 265.65 | 275.65 | 6.4938 | 9.0632 -1 | 0.8516 | 1.1454 +0 |
| 48.365 | 48.000 | 0.0 | 0.0 | 265.65 | 275.65 | 0.8399 | 1.1613 +0 | 1.1014 | 1.4677 |
| 47.350 | 47.000 | xxx | xxx | 265.65 | 275.65 | 0.9551 | 1.3145 | 1.2525 | 1.6613 |
| 46.335 | 46.000 | +3.1 | +2.5 | 262.55 | 273.15 | 1.0870 | 1.4888 | 1.4423 | 1.8988 |
| 44.307 | 44.000 | +3.1 | +2.5 | 256.35 | 268.15 | 1.4145 | 1.9164 | 1.9223 | 2.4897 |
| 42.279 | 42.000 | +3.1 | +2.5 | 250.15 | 263.15 | 1.8526 | 2.4785 | 2.5800 | 3.2812 |
| 40.253 | 40.000 | +3.1 | +2.5 | 243.95 | 258.15 | 2.4429 | 3.2214 | 3.4886 | 4.3472 |
| 38.229 | 38.000 | +3.1 | +2.5 | 237.75 | 253.15 | 3.2443 | 4.2084 | 4.7538 | 5.7914 |
| 36.205 | 36.000 | +3.1 | +2.5 | 231.55 | 248.15 | 4.3410 | 5.5722 | 6.5311 | 7.8227 +0 |
| 34.183 | 34.000 | +3.1 | +2.5 | 225.35 | 243.15 | 5.8545 | 7.2998 | 0.9051 | 1.0459 +1 |
| 32.162 | 32.000 | xxx | xxx | 219.15 | 238.15 | 7.9616 | 9.6966 +0 | 1.2656 | 1.4184 |
| 30.142 | 30.000 | +0.8 | +2.1 | 217.55 | 233.95 | 1.0887 | 1.2952 +1 | 1.7434 | 1.9287 |
| 28.124 | 28.000 | +0.8 | +2.1 | 215.95 | 229.75 | 1.4921 | 1.7391 | 2.4071 | 2.6370 |
| 27.115 | 27.000 | xxx | xxx | 215.15 | 227.65 | 1.7484 | 2.0193 | 2.8310 | 3.0901 |
| 26.107 | 26.000 | 0.0 | +1.2 | 215.15 | 226.45 | 2.0493 | 2.3472 | 3.3182 | 3.6109 |
| 24.091 | 24.000 | 0.0 | +1.2 | 215.15 | 224.05 | 2.8153 | 3.1790 | 4.5584 | 4.9430 |
| 22.076 | 22.000 | 0.0 | +1.2 | 215.15 | 221.65 | 3.8677 | 4.3197 | 6.2627 | 6.7893 |
| 20.063 | 20.000 | 0.0 | +1.2 | 215.15 | 219.25 | 5.3134 | 5.8892 | 8.6034 | 9.3575 +1 |
| 19.057 | 19.000 | xxx | +1.2 | 215.15 | 218.05 | 6.2278 | 6.8852 | 1.0084 | 1.1000 +2 |
| 18.051 | 18.000 | -0.5 | +1.2 | 215.65 | 216.85 | 7.2981 | 8.0565 | 1.1790 | 1.2943 |
| 17.046 | 17.000 | -0.5 | xxx | 216.15 | 215.65 | 8.5492 | 9.4353 +1 | 1.3779 | 1.5242 |
| 16.040 | 16.000 | -0.5 | 0.0 | 216.65 | 215.65 | 1.0011 | 1.1055 +2 | 1.6098 | 1.7859 |
| 14.031 | 14.000 | -0.5 | 0.0 | 217.65 | 215.65 | 1.3713 | 1.5176 | 2.1949 | 2.4516 |
| 13.027 | 13.000 | -0.5 | xxx | 218.15 | 215.65 | 1.6041 | 1.7781 | 2.5616 | 2.8724 |
| 12.023 | 12.000 | -0.5 | -6.5 | 218.65 | 222.15 | 1.8757 | 2.0784 | 2.9885 | 3.2593 |
| 10.016 | 10.000 | xxx | -6.5 | 219.65 | 235.15 | 2.5620 | 2.8025 | 4.0634 | 4.1515 |
| 8.010 | 8.000 | -6.0 | -6.5 | 231.65 | 248.15 | 3.4682 | 3.7184 | 5.2155 | 5.2189 |
| 6.006 | 6.000 | -6.0 | xxx | 243.65 | 261.15 | 4.6236 | 4.8625 | 6.6096 | 6.4828 |
| 4.003 | 4.000 | -6.0 | -6.0 | 255.65 | 273.15 | 6.0789 | 6.2782 | 8.2797 | 7.9955 |
| 3.001 | 3.000 | xxx | -6.0 | 261.65 | 279.15 | 6.9367 | 7.1034 | 9.2287 | 8.8451 +2 |
| 2.001 | 2.000 | -3.5 | xxx | 265.15 | 285.15 | 7.8964 | 8.0150 +2 | 1.0364 | 9.7560 +3 |
| 0.000 | 0.000 | -3.5 | -4.5 | 272.15 | 294.15 | 1.0180 | 1.0135 +3 | 1.3010 | 1.1920 +3 |

* Power of ten by which preceding figures should be multiplied.

Table 2. Properties to 90 km of Subtropical (30°N) Atmosphere, Winter and Summer

| Kilometers | | Temp. Grad. | | Temp. (K) | | Pressure (mbs) | | | Density ( g / m$^3$) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Geomet | Geopot | Win | Sum | Win | Sum | Win | Sum | * | Win | Sum | * |
| 90.000 | 88.680 | 0.0 | 0.0 | 191.15 | 178.65 | 1.8916 | 1.7297 | -3 | 3.4474 | 3.3729 | -3 |
| 89.301 | 88.000 | 0.0 | 0.0 | 191.15 | 178.65 | 2.1357 | 1.9695 | | 3.8923 | 3.8411 | |
| 87.244 | 86.000 | 0.0 | 0.0 | 191.15 | 178.65 | 3.0518 | 2.8856 | | 5.5619 | 5.6270 | |
| 85.188 | 84.000 | 0.0 | 0.0 | 191.15 | 178.65 | 4.3608 | 4.2277 | | 7.9476 | 8.2441 | -3 |
| 83.133 | 82.000 | 0.0 | 0.0 | 191.15 | 178.65 | 6.2314 | 6.1941 | | 1.1357 | 1.2079 | -2 |
| 81.078 | 80.000 | 0.0 | 0.0 | 191.15 | 178.65 | 8.9044 | 9.0752 | -3 | 1.6228 | 1.7697 | |
| 80.053 | 79.000 | xxx | xxx | 191.15 | 178.65 | 1.0644 | 1.0985 | -2 | 1.9399 | 2.1421 | |
| 79.028 | 78.000 | -3.1 | -3.7 | 194.25 | 182.35 | 1.2705 | 1.3270 | | 2.2785 | 2.2352 | |
| 76.978 | 76.000 | -3.1 | -3.7 | 200.45 | 189.15 | 1.7954 | 1.9151 | | 3.1203 | 3.5160 | |
| 74.928 | 74.000 | -3.1 | -3.7 | 206.65 | 197.15 | 2.5104 | 2.7251 | | 4.2320 | 4.8153 | |
| 72.879 | 72.000 | -3.1 | -3.7 | 212.85 | 204.55 | 3.4757 | 3.8277 | | 5.6887 | 6.5190 | |
| 70.830 | 70.000 | -3.1 | -3.7 | 219.05 | 211.95 | 4.7673 | 5.3120 | | 7.5818 | 8.7311 | -2 |
| 68.786 | 68.000 | -3.1 | -3.7 | 225.25 | 219.35 | 6.4815 | 7.2892 | | 1.0024 | 1.1577 | -1 |
| 66.742 | 66.000 | -3.1 | -3.7 | 231.45 | 226.75 | 8.7389 | 9.8981 | -2 | 1.3154 | 1.5207 | |
| 64.699 | 64.000 | -3.1 | -3.7 | 237.65 | 234.15 | 1.1689 | 1.3309 | -1 | 1.7135 | 1.9801 | |
| 62.657 | 62.000 | -3.1 | -3.7 | 243.85 | 241.55 | 1.5520 | 1.7732 | | 2.2172 | 2.5574 | |
| 60.615 | 60.000 | -3.1 | -3.7 | 250.05 | 248.95 | 2.0460 | 2.3420 | | 2.8505 | 3.2773 | |
| 59.596 | 59.000 | xxx | xxx | 253.15 | 252.65 | 2.3431 | 2.6833 | | 3.2244 | 3.6999 | |
| 58.578 | 58.000 | -2.0 | -2.5 | 255.15 | 255.15 | 2.6798 | 3.0692 | | 3.6589 | 4.1906 | |
| 56.541 | 56.000 | -2.0 | -2.5 | 259.15 | 260.15 | 3.4941 | 3.9998 | | 4.6971 | 5.3562 | |
| 54.504 | 54.000 | -2.0 | -2.5 | 263.15 | 265.15 | 4.5374 | 5.1865 | | 6.0068 | 6.8144 | |
| 52.468 | 52.000 | -2.0 | -2.5 | 267.15 | 270.15 | 5.8691 | 6.6926 | | 7.6535 | 8.6304 | |
| 51.450 | 51.000 | xxx | xxx | 269.15 | 272.65 | 6.6654 | 7.5890 | | 8.6273 | 9.6966 | -1 |
| 50.432 | 50.000 | 0.0 | 0.0 | 269.15 | 272.65 | 7.5661 | 8.6006 | -1 | 0.9793 | 1.0989 | +0 |
| 48.401 | 48.000 | 0.0 | 0.0 | 269.15 | 272.65 | 0.9749 | 1.1046 | +0 | 1.2619 | 1.4114 | |
| 47.385 | 47.000 | xxx | xxx | 269.15 | 272.65 | 1.1067 | 1.2519 | | 1.4324 | 1.5996 | |
| 46.370 | 46.000 | +2.4 | +2.4 | 266.75 | 270.25 | 1.2570 | 1.4195 | | 1.6416 | 1.8298 | |
| 44.340 | 44.000 | +2.4 | +2.4 | 261.95 | 265.45 | 1.6271 | 1.8314 | | 2.1639 | 2.4035 | |
| 42.311 | 42.000 | +2.4 | +2.4 | 257.15 | 260.65 | 2.1164 | 2.3738 | | 2.8672 | 3.1727 | |
| 40.282 | 40.000 | +2.4 | +2.4 | 252.35 | 255.85 | 2.7665 | 3.0916 | | 3.8192 | 4.2096 | |
| 38.258 | 38.000 | +2.4 | +2.4 | 247.55 | 251.05 | 3.6348 | 4.0468 | | 5.1152 | 5.6156 | |
| 36.233 | 36.000 | +2.4 | +2.4 | 242.75 | 246.25 | 4.8014 | 5.3246 | | 6.8905 | 7.5327 | +0 |
| 34.209 | 34.000 | +2.4 | +2.4 | 237.95 | 241.45 | 6.3777 | 7.0440 | | 0.9337 | 1.0163 | +1 |
| 32.186 | 32.000 | xxx | xxx | 233.15 | 236.65 | 8.5207 | 9.3710 | +0 | 1.2732 | 1.3795 | |
| 30.163 | 30.000 | +2.0 | +2.0 | 229.15 | 232.65 | 1.1447 | 1.2534 | +1 | 1.7403 | 1.8768 | |
| 28.144 | 28.000 | +2.0 | +2.0 | 225.15 | 228.65 | 1.5458 | 1.6848 | | 2.3918 | 2.5670 | |
| 26.125 | 26.000 | +2.0 | +2.0 | 221.15 | 224.65 | 2.0986 | 2.2767 | | 3.3059 | 3.5306 | |
| 24.108 | 24.000 | +2.0 | +2.0 | 217.15 | 220.65 | 2.8652 | 3.0932 | | 4.5966 | 4.8836 | |
| 22.092 | 22.000 | xxx | +2.0 | 213.15 | 216.65 | 3.9346 | 4.2261 | | 6.4307 | 6.7955 | |
| 21.084 | 21.000 | +2.5 | xxx | 210.65 | 214.65 | 4.6219 | 4.9505 | | 7.6437 | 8.0345 | |
| 20.077 | 20.000 | +2.5 | +2.3 | 208.15 | 212.35 | 5.4398 | 5.8083 | | 9.1043 | 9.5287 | +1 |
| 18.064 | 18.000 | xxx | +2.3 | 203.15 | 207.75 | 7.5803 | 8.0377 | | 1.2999 | 1.3478 | +2 |
| 17.057 | 17.000 | xxx | +2.3 | 203.15 | 205.45 | 8.9665 | 9.4809 | +1 | 1.5376 | 1.6076 | |
| 16.052 | 16.000 | -2.6 | xxx | 205.75 | 203.15 | 1.0595 | 1.1204 | +2 | 1.7939 | 1.9213 | |
| 15.046 | 15.000 | -2.6 | xxx | 208.35 | 203.15 | 1.2493 | 1.3253 | | 2.0889 | 2.2727 | |
| 14.041 | 14.000 | -2.6 | -7.0 | 210.95 | 210.15 | 1.4700 | 1.5632 | | 2.4276 | 2.5914 | |
| 12.031 | 12.000 | xxx | -7.0 | 216.15 | 224.15 | 2.0235 | 2.1405 | | 3.2613 | 3.3267 | |
| 10.023 | 10.000 | -6.5 | -7.0 | 229.15 | 238.15 | 2.7494 | 2.8758 | | 4.1798 | 4.2062 | |
| 8.016 | 8.000 | -6.5 | -7.0 | 242.15 | 252.15 | 3.6728 | 3.7987 | | 5.2830 | 5.2458 | |
| 6.010 | 6.000 | -6.5 | xxx | 255.15 | 266.15 | 4.8326 | 4.9422 | | 6.5961 | 6.4619 | |
| 4.005 | 4.000 | -6.5 | -5.5 | 268.15 | 277.15 | 6.2717 | 6.3508 | | 8.1407 | 7.9634 | |
| 2.002 | 2.000 | xxx | -5.5 | 281.15 | 288.15 | 8.0375 | 8.0778 | | 9.9341 | 9.7192 | +2 |
| 1.001 | 1.000 | -3.0 | xxx | 284.15 | 293.65 | 9.0652 | 9.0770 | +2 | 1.1072 | 1.0698 | +3 |
| 0.000 | 0.000 | -3.0 | -7.5 | 287.15 | 301.15 | 1.0210 | 1.0170 | +3 | 1.2328 | 1.1632 | +3 |

*Power of ten by which preceding figures should be multiplied.

Table 3. Properties to 90 km of Tropical (15°N) Atmosphere

| Kilometers Geomet | Kilometers Geopot | Temperature Grad. | Temperature Kelvin | Pressure mbs * | Density g / m³ * |
|---|---|---|---|---|---|
| 90.000 | 88.597 | 0.0 | 184.15 | 1.8620 -3 | 3.5224 -3 |
| 89.388 | 88.000 | 0.0 | 184.15 | 2.0796 | 3.9342 |
| 87.330 | 86.000 | 0.0 | 184.15 | 3.0113 | 5.6966 |
| 85.272 | 84.000 | 0.0 | 184.15 | 4.3603 | 8.2487 -3 |
| 83.214 | 82.000 | 0.0 | 184.15 | 6.3137 | 1.1944 -2 |
| 81.156 | 80.000 | 0.0 | 184.15 | 9.1422 -3 | 1.7295 |
| 80.130 | 79.000 | xxx | 184.15 | 1.1001 -2 | 2.0811 |
| 79.104 | 78.000 | -3.5 | 187.65 | 1.3215 | 2.4534 |
| 77.052 | 76.000 | -3.5 | 194.65 | 1.8878 | 3.3786 |
| 75.000 | 74.000 | -3.5 | 201.65 | 2.6630 | 4.6006 |
| 72.949 | 72.000 | -3.5 | 208.65 | 3.7128 | 6.1989 |
| 70.898 | 70.000 | -3.5 | 215.65 | 5.1199 | 8.2710 -2 |
| 68.852 | 68.000 | -3.5 | 222.65 | 6.9881 | 1.0934 -1 |
| 66.806 | 66.000 | -3.5 | 229.65 | 9.4466 -2 | 1.4330 |
| 64.761 | 64.000 | -3.5 | 236.65 | 1.2655 -1 | 1.8629 |
| 62.717 | 62.000 | -3.5 | 243.65 | 1.6809 | 2.4033 |
| 60.673 | 60.000 | -3.5 | 250.65 | 2.2148 | 3.0783 |
| 59.652 | 59.000 | xxx | 254.15 | 2.5351 | 3.4749 |
| 58.634 | 58.000 | -2.0 | 256.15 | 2.8974 | 3.9404 |
| 56.595 | 56.000 | -2.0 | 260.15 | 3.7730 | 5.0524 |
| 54.556 | 54.000 | -2.0 | 264.15 | 4.8935 | 6.4536 |
| 52.518 | 52.000 | -2.0 | 268.15 | 6.3221 | 8.2135 |
| 51.498 | 51.000 | xxx | 270.15 | 7.1756 | 9.2534 -1 |
| 50.480 | 50.000 | 0.0 | 270.15 | 8.1405 -1 | 1.0497 0 |
| 48.448 | 48.000 | 0.0 | 270.15 | 1.0477 0 | 1.3511 |
| 47.432 | 47.000 | xxx | 270.15 | 1.1886 | 1.5328 |
| 46.416 | 46.000 | +2.2 | 267.95 | 1.3492 | 1.7542 |
| 44.384 | 44.000 | +2.2 | 263.55 | 1.7437 | 2.3049 |
| 42.352 | 42.000 | +2.2 | 259.15 | 2.2633 | 3.0425 |
| 40.320 | 40.000 | +2.2 | 254.75 | 2.9510 | 4.0355 |
| 38.293 | 38.000 | +2.2 | 250.35 | 3.8654 | 5.3788 |
| 36.267 | 36.000 | +2.2 | 245.95 | 5.0874 | 7.2061 |
| 34.242 | 34.000 | +2.2 | 241.55 | 6.7291 | 9.7049 0 |
| 32.217 | 32.000 | +2.2 | 237.15 | 8.9464 0 | 1.3142 +1 |
| 30.192 | 30.000 | +2.2 | 232.75 | 1.1958 +1 | 1.7898 |
| 28.171 | 28.000 | +2.2 | 228.35 | 1.6072 | 2.4519 |
| 26.150 | 26.000 | +2.2 | 223.95 | 2.1726 | 3.3797 |
| 24.131 | 24.000 | +2.2 | 219.55 | 2.9546 | 4.6884 |
| 22.113 | 22.000 | xxx | 215.15 | 4.0430 | 6.5466 |
| 20.096 | 20.000 | +4.0 | 207.15 | 5.5838 | 9.3903 +1 |
| 18.081 | 18.000 | +4.0 | 199.15 | 7.8106 +1 | 1.3663 +2 |
| 16.570 | 16.500 | xxx | 193.15 | 1.0137 +2 | 1.8284 |
| 16.067 | 16.000 | -6.7 | 196.50 | 1.1063 | 1.9613 |
| 14.054 | 14.000 | -6.7 | 209.90 | 1.5474 | 2.5682 |
| 12.043 | 12.000 | -6.7 | 223.30 | 2.1200 | 3.3074 |
| 10.032 | 10.000 | -6.7 | 236.70 | 2.8516 | 4.1965 |
| 8.023 | 8.000 | -6.7 | 250.10 | 3.7733 | 5.2545 |
| 6.016 | 6.000 | -6.7 | 263.50 | 4.9201 | 6.4996 |
| 4.009 | 4.000 | -6.7 | 276.90 | 6.3303 | 7.9509 |
| 2.505 | 2.500 | xxx (+3.2) | 286.95 | 7.5861 | 9.1845 |
| 2.254 | 2.250 | xxx | 286.15 | 7.8133 | 9.4604 |
| 2.004 | 2.000 | -6.0 | 287.65 | 8.0475 | 9.6896 +2 |
| 1.002 | 1.000 | -6.0 | 293.65 | 9.0417 | 1.0645 +3 |
| 0.000 | 0.000 | -6.0 | 299.65 | 10.1325 +2 | 1.1666 +3 |

*Power of 10 by which preceding figures should be multiplied.

## Table 4. Moisture Properties to 10 Km of the Supplemental Atmospheres

Table 4a. Mid-Latitude (45°N) Atmospheres, Winter and Summer

| Kilometers Geomet | Kilometers Geopot | Temp Grad Win | Temp Grad Sum | Temp (K) Win | Temp (K) Sum | Virtual Temp(K) Win | Virtual Temp(K) Sum | Rel Hum(%) Win | Rel Hum(%) Sum | Pressure (mb) Win | Pressure (mb) Sum | Density(g/m$^3$) Win | Density(g/m$^3$) Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10.016 | 10.000 | xxx | -6.5 | 219.65 | 235.15 | 219.654 | 235.172 | 30 = | 30 | 256.20 | 280.25 | 406.34 | 415.15 |
| 8.010 | 8.000 | -6.0 | -6.5 | 231.65 | 248.15 | 231.664 | 248.211 | 35 | 30 | 346.82 | 371.84 | 521.55 | 521.89 |
| 6.005 | 6.000 | -6.0 | xxx | 243.65 | 261.15 | 243.698 | 261.299 | 45 | 30 | 462.36 | 486.25 | 660.96 | 648.28 |
| 4.003 | 4.000 | -6.0 = | -6.0 | 255.65 | 273.15 | 255.774 | 273.552 | 50 | 40 | 607.89 | 627.82 | 827.97 | 799.55 |
| 3.001 | 3.000 | xxx | -6.0 | 261.65 | 279.15 | 261.850 | 279.777 | 55 | 45 | 693.67 | 710.34 | 922.87 | 884.51 |
| 2.001 | 2.000 | -3.5 | xxx | 265.15 | 285.15 | 265.427 | 286.192 | 65 | 55 | 789.64 | 801.50 | 1036.40 | 975.65 |
| 1.000 | 1.000 | -3.5 | -4.5 | 268.65 | 289.65 | 268.998 | 291.142 | 70 | 65 | 897.34 | 902.20 | 1162.13 | 1079.53 |
| 0.000 | 0.000 | -3.5 | -4.5 | 272.15 | 294.15 | 272.594 | 296.216 | 77 | 75 | 1018.00 | 1013.50 | 1300.99 | 1191.95 |

Table 4b. Subtropical (30°N) Atmospheres, Winter and Summer

| Kilometers Geomet | Kilometers Geopot | Temp Grad Win | Temp Grad Sum | Temp (K) Win | Temp (K) Sum | Virtual Temp(K) Win | Virtual Temp(K) Sum | Rel Hum(%) Win | Rel Hum(%) Sum | Pressure (mb) Win | Pressure (mb) Sum | Density(g/m$^3$) Win | Density(g/m$^3$) Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10.023 | 10.000 | -6.5 | -7.0 | 229.15 | 238.15 | 229.162 | 238.179 | 30 = | 30 | 274.94 | 287.58 | 417.98 | 420.62 |
| 8.016 | 8.000 | -6.5 | -7.0 | 242.15 | 252.15 | 242.185 | 252.266 | 30 | 40 | 367.28 | 379.87 | 528.30 | 524.58 |
| 6.010 | 6.000 | -6.5 | xxx | 255.15 | 266.15 | 255.239 | 266.445 | 30 | 40 | 483.26 | 494.22 | 659.61 | 646.19 |
| 4.005 | 4.000 | -6.5 | -5.5 | 268.15 | 277.15 | 268.389 | 277.823 | 35 | 50 | 627.17 | 635.08 | 814.07 | 796.34 |
| 3.003 | 3.000 | -6.5 | -5.5 | 274.65 | 282.65 | 275.098 | 283.716 | 45 | 60 | 711.07 | 717.13 | 900.47 | 880.54 |
| 2.002 | 2.000 | xxx | -5.5 | 281.15 | 288.15 | 281.862 | 289.536 | 50 | 60 | 803.75 | 807.78 | 993.41 | 971.92 |
| 1.001 | 1.000 | -3.0 | xxx | 284.15 | 293.65 | 285.244 | 295.580 | 70 | 65 | 906.52 | 907.70 | 1107.16 | 1069.81 |
| 0.000 | 0.000 | -3.0 | -7.5 | 287.15 | 301.15 | 288.519 | 304.583 | 80 = | 80 | 1021.00 | 1017.00 | 1232.80 | 1163.21 |

Table 4c. Tropical (15°N) Atmosphere

| Kilometers Geomet | Kilometers Geopot | Temp Grad | Temp (K) | Virtual Temp(K) | Rel Hum(%) | Pressure (mb) | Density(g/m$^3$) |
|---|---|---|---|---|---|---|---|
| 10.032 | 10.000 | -6.7 | 236.70 | 236.717 | 20 | 285.16 | 419.65 |
| 8.023 | 8.000 | -6.7 | 250.10 | 250.172 | 30 | 377.33 | 525.45 |
| 6.016 | 6.000 | -6.7 | 263.50 | 263.709 | 35 | 492.01 | 649.96 |
| 4.009 | 4.000 | -6.7 | 276.90 | 277.363 | 35 | 633.03 | 795.09 |
| 2.505 | 2.500 | xxx | 286.95 | 287.743 | 35 | 758.61 | 918.45 |
| | | +3.2 | | | | | |
| 2.254 | 2.250 | xxx | 286.15 | 287.717 | 75 | 781.33 | 946.04 |
| 2.004 | 2.000 | -6.0 | 287.65 | 289.336 | 75 | 804.75 | 968.96 |
| 1.002 | 1.000 | -6.0 | 293.65 | 295.893 | 75 | 904.17 | 1064.53 |
| 0.000 | 0.000 | -6.0 | 299.65 | 302.588 | 75 | 1013.25 | 1166.56 |

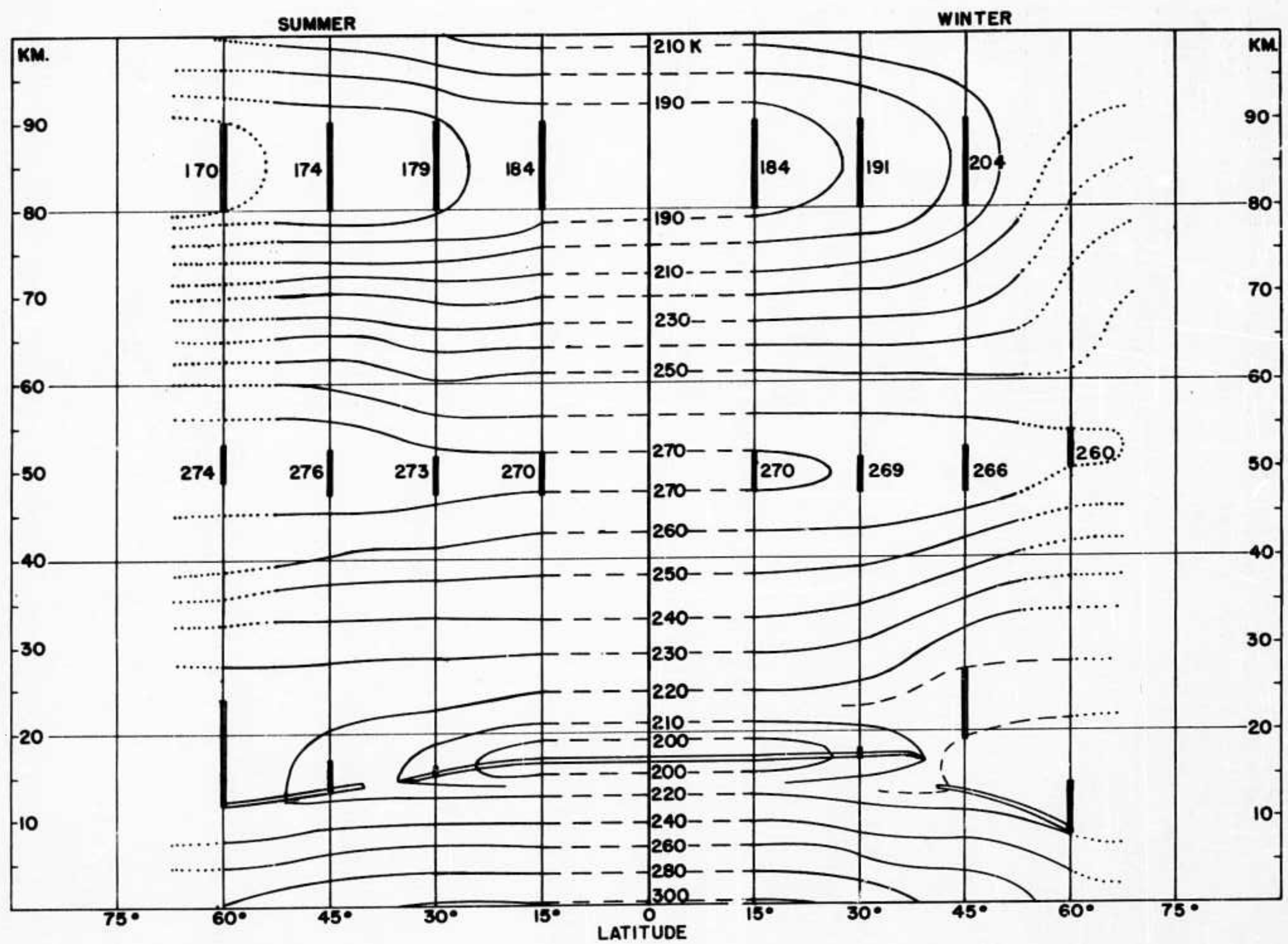


Figure 1. Latitudinal temperature-height cross section of the Supplemental Atmospheres (60°N tentative) winter (right) and summer (left). Double vertical lines, isothermal; double horizontal line, tropopause.

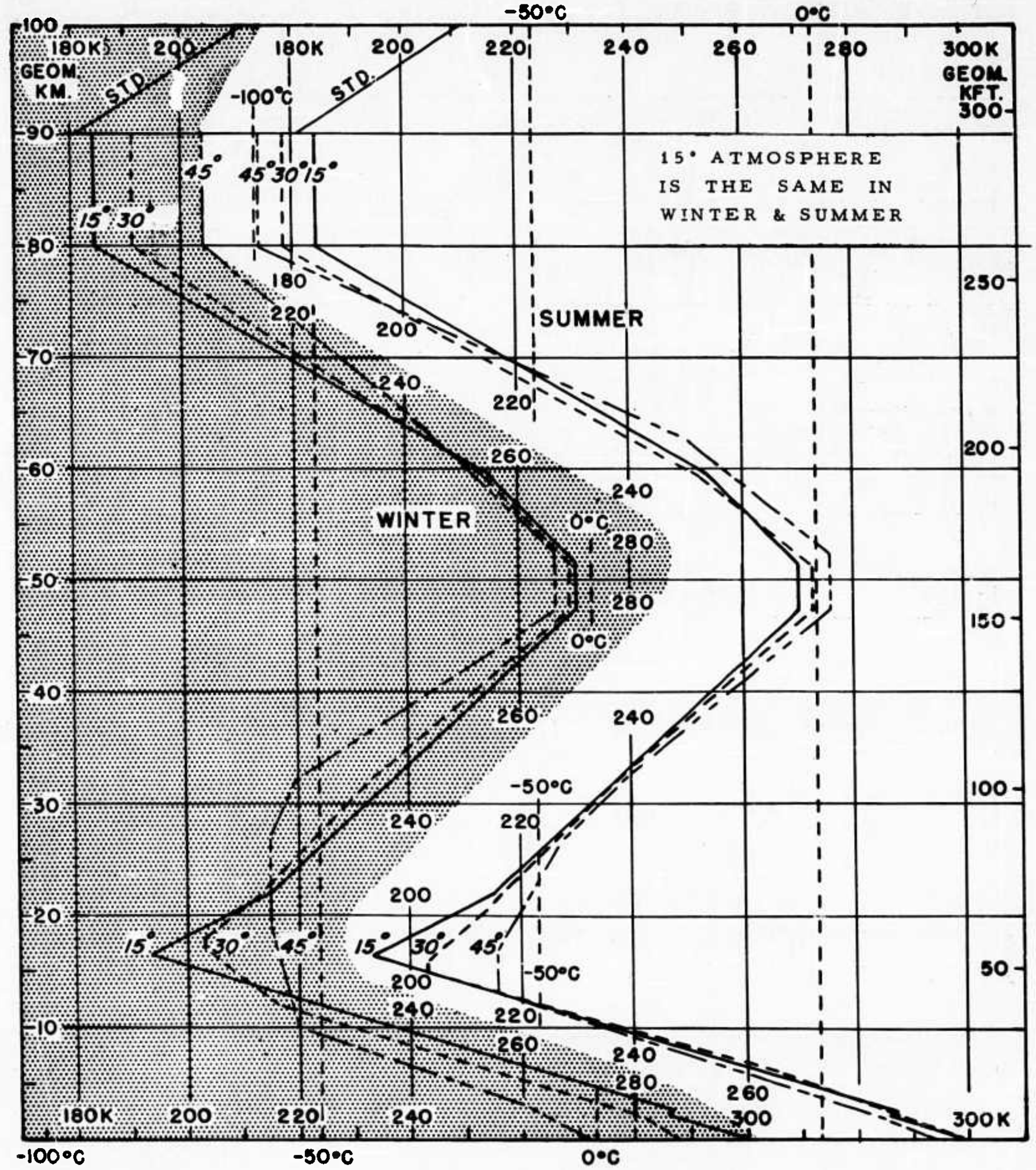


Figure 2. Temperature-height profiles of Supplemental Atmospheres, winter (left) and summer (right).

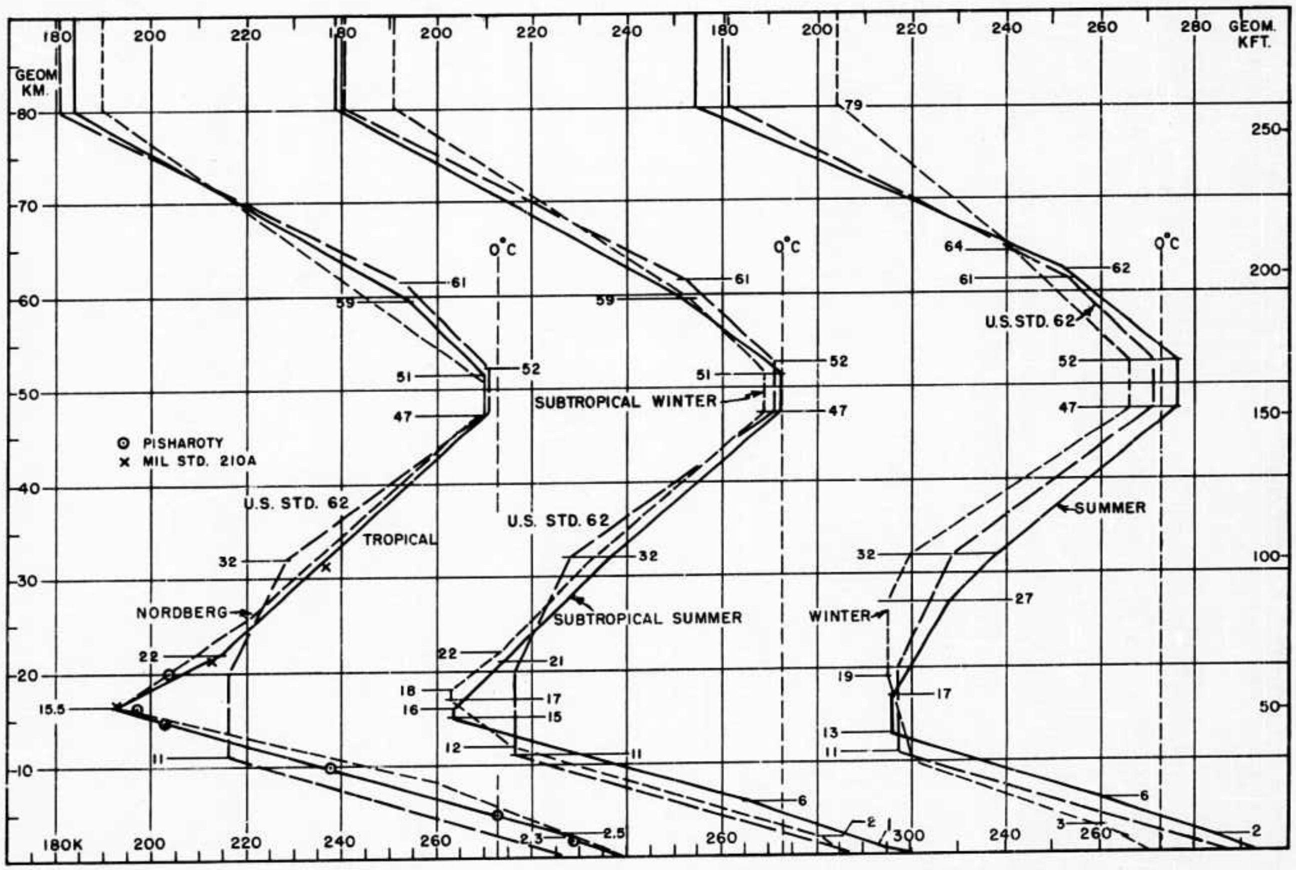


Figure 3. Supplemental Atmospheres compared with the U. S. Standard Atmosphere, 1962, and other atmospheres: (left), mean annual Tropical (15°N) temperature-height profile and three low-latitude Model Atmospheres; (center), Subtropical (30°N) temperature-height profiles, winter and summer.

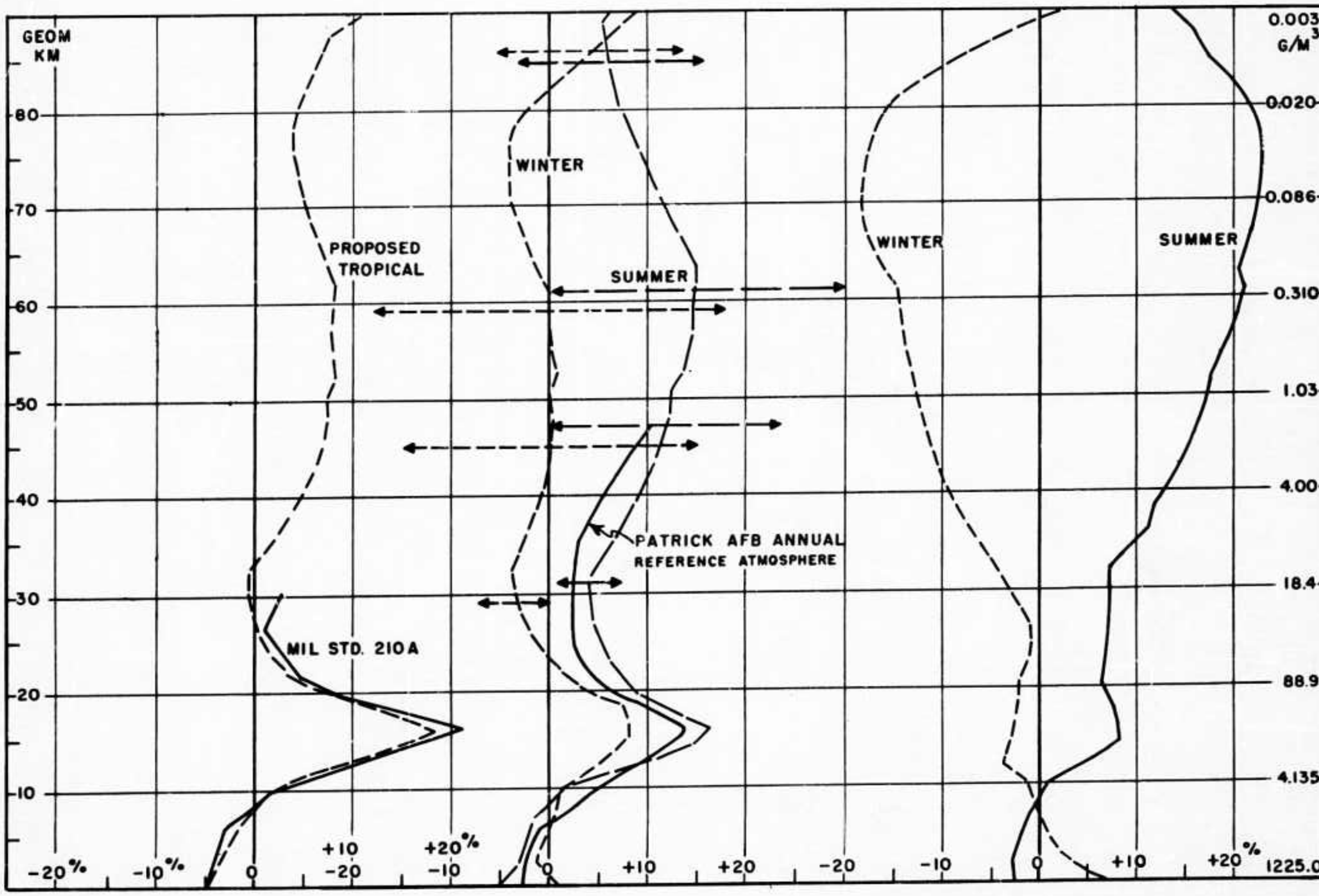


Figure 4. Density departures (percent) of Supplemental Atmospheres from the U. S. Standard Atmosphere, 1962: (left), Tropical (15°N), MIL-STD 210A Tropical, and Nordberg's Low-Latitude Atmospheres; (center), Subtropical (30°N) Atmospheres, winter and summer and Patrick AFB Annual Reference Atmosphere; (right), Mid-Latitude (45°N) Atmospheres, winter and summer.

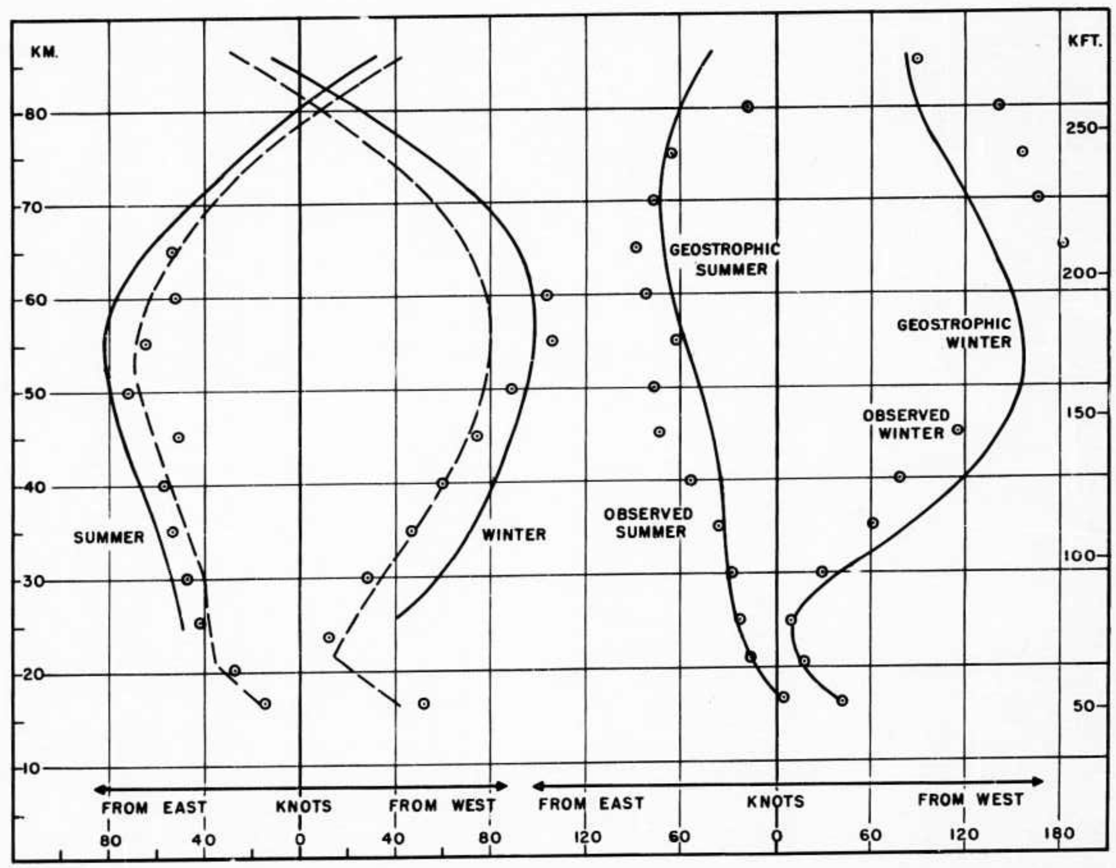


Figure 5. Zonal wind components. Left, between 25° and 30°N, geostrophic components computed (solid lines) from Tropical (annual) and Subtropical (seasonal) atmospheres, and (dashed lines) frcm seasonal data at both 15°N and 30°N; circles show observed mean seasonal components at Patrick AFB. Right, between 30° and 45°N, winter and summer geostrophic components computed from Subtropical and Midlatitude atmospheres, with observed winter and summer components at 38°N (circles).

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# Appendix

DATA SOURCES

1. Radiosonde temperature-height summaries:

   a. Caribbean and U. S. (Jordan, 1958, Ratner, 1957, USWB, 1956-61).

   b. Atlantic and Pacific Oceans, Europe, Africa, and Asia (Borden, 1960, Goldie et al, 1958, Faust and Attmannspacher, 1959, McDonald, 1959, Pisharoty, 1959, U. S. Navy, 1955-56, USWB, 1956-61, Wege, 1958).

2. Rocket and searchlight observations of temperature, pressure and density:

   a. Rocket-grenade measurements: 12 at White Sands; 10 at Ft. Churchill (Stroud et al, 1956, 1960); 9 at Guam (Nordberg and Stroud, 1961); 4 at Woomera, Australia (Boyd and Groves, 1961).

   b. Pressure-gage flights: 7 at White Sands and Holloman AFB; 15 at Ft. Churchill; 1 at the equator (Ainsworth et al, 1961; Dow and Spencer, 1953; Havens et al, 1952; LaGow and Ainsworth, 1956; Newell, 1960; Ripley, 1960; Sicinski et al, 1954; Spencer et al, 1958).

   c. Falling-sphere flights: 4 at White Sands; 2 at Wallops Island; 3 in the North Atlantic; 4 at Ft. Churchill (Jones and Peterson, (1961).

   d. Searchlight probes: 18 density profiles for New Mexico (Elterman, 1954).

   e. Meteorological rocket flights: several dozen from the eight stations in the Meteorological Rocket Network (USASMSA, 1959-61).

   f. Atmospheric density: Summary of observations between 30 and 80 km (Quiroz, 1961, Thiele, 1961).

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AF Cambridge Research Laboratories, Bedford, Mass. Geophysics Research Directorate
SUPPLEMENTAL ATMOSPHERES, by A. Court, A.J. Kantor, and A.E. Cole. September 1962. 21 pp. incl. illus. tables. AFCRL-62-899
Unclassified report

Atmospheres typical of the tropics, subtropics, and mid-latitudes are prepared as part of a family supplemental to the 1962 U.S. Standard Atmosphere; they provide information on latitudinal and seasonal changes in atmospheric structure up to 90 km. Temperature gradients for various segments are linear with geopotential height. Humidity is incorporated into the lowermost 10 km of each atmosphere. Figures and tables depict temperature, relative humidity, pressure, and density. The atmospheres are mutually consistent; zonal wind profiles computed from the geostrophic wind equation at selected pressure heights compare favorably with existing rawinsonde and Meteorological Rocket Network wind observations.

1. Atmosphere model
2. Meteorology

I. Court, A.
II. Kantor, A.J.
III. Cole, A.E.

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2. Meteorology

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